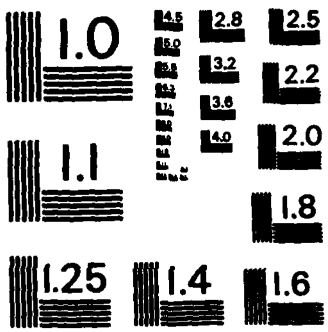
AD-A159 367 RESULTS OF OPERATIONAL TESTING OF LASS-II (LITTON AUTO-SURVEYOR SYSTEM) SYSTEMS(U) DEFENSE MAPPING AGENCY WASHINGTON DC L PFEIFER ET AL. SEP 85 1/1

UNCLASSIFIED F/G 8/5 NL


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

AD-A159 367

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188
Exp. Date: Jun 30, 1986

REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS N/A
SECURITY CLASSIFICATION AUTHORITY N/A	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for Public Release; Distribution unlimited
DECLASSIFICATION/DOWNGRADING SCHEDULE n/a	
PERFORMING ORGANIZATION REPORT NUMBER(S) N/A	5. MONITORING ORGANIZATION REPORT NUMBER(S) N/A
NAME OF PERFORMING ORGANIZATION efense Mapping Agency — 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION N/A
ADDRESS (City, State, and ZIP Code) Washington, D.C. 20305-3000	7b. ADDRESS (City, State, and ZIP Code) N/A
NAME OF FUNDING/SPONSORING ORGANIZATION DMA Hydrographic/Topographic — 8b. OFFICE SYMBOL (If applicable) GSST	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N/A
8c. ADDRESS (City, State, and ZIP Code) Washington, D.C. 20315	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
n/a	n/a	n/a	n/a

11. TITLE (Include Security Classification)

Results of Operational Testing of LASS-II Systems

12. PERSONAL AUTHOR(S)
L. Pfeifer and R. Tyszka

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
FINAL	FROM Aug 84 TO May 85	September 1985	13

16 SUPPLEMENTARY NOTATION

3rd International Symposium on Inertial Technology, 16-20 Sep 85, Banff, Canada

17 COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	
08	05		Inertial Surveying Litton Auto Survey System II (LASS II

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The Defense Mapping Agency has been active in the field of inertial surveying since 1975. More recently, delivery was taken of two Litton Auto-Surveyor System II (LASS-II) units. This paper descirbes the testing carried out with these two systems over the Cheyenne IPS Test Course and presents a statistical analysis of the results obtained. New mathematical models for the RMS error of interpolated position and height as a function of traverse length are proposed.

DTIC FILE COPY

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a NAME OF RESPONSIBLE INDIVIDUAL Ludvik Pfeifer	22b. TELEPHONE (Include Area Code) 307-775-3119 — 22c. OFFICE SYMBOL GSST

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

A159 367

RESULTS OF OPERATIONAL TESTING
OF LASS-II SYSTEMS

by

L. Pfeifer

R. Tyszka

Defense Mapping Agency
Washington, DC 20305-3000
USA

1. INTRODUCTION

The Department of Defense, Defense Mapping Agency (DMA) has operated inertial surveying systems since 1975 when a Litton Auto-Surveyor System (LASS) unit was acquired. Designated the Inertial Positioning System One (IPS-1), this unit is still operational in its eleventh year of service and is frequently utilized for routine surveying tasks. Experience was also gained with extensive testing and limited operational use of a prototype of the Honeywell GEO-SPIN system, known in DMA as IPS-2 (1979-82), and with the standard U.S. Army Position and Azimuth Determining System (PADS) of which two units were acquired in 1982.

These two PADS units have now been upgraded to the configuration of the Litton Auto-Surveyor System II (LASS-II) and bear the DMA designation of IPS-3 and IPS-4. The purpose of this paper is to present the results of operational testing of these LASS-II systems carried out in the span of the past year over the Cheyenne IPS Test Course.

2. LASS II

The Litton Auto-Surveyor System II is an upgraded version of the Position and Azimuth Determining System intended for applications in surveying and geodesy. The hardware features which set a LASS-II apart from a PADS are (1) gyros screened to tighter performance specifications, (2) modifications to the control/display unit (CDU), (3) addition of a digital tapedeck and associated interface electronics, and (4) a coat of paint change from olive drab to off-white which, aside from giving the LASS-II a distinctive look, has the functional

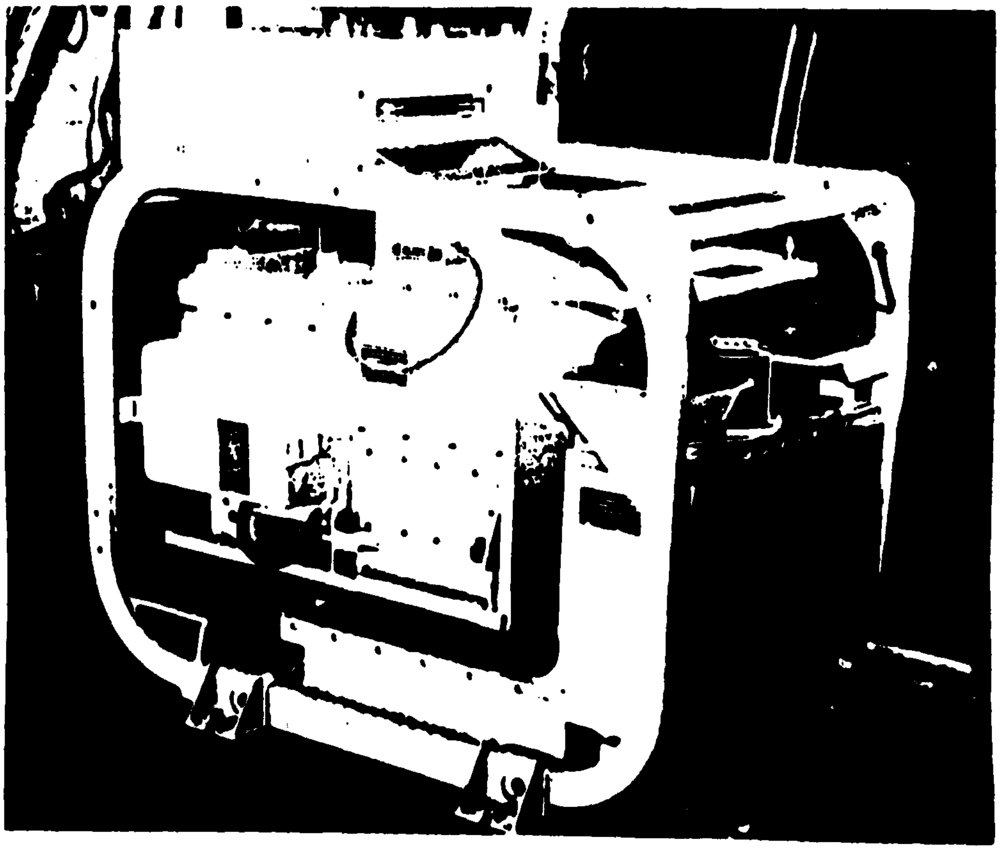


Figure 1. Litton Auto-Surveyor System II (LASS-II)

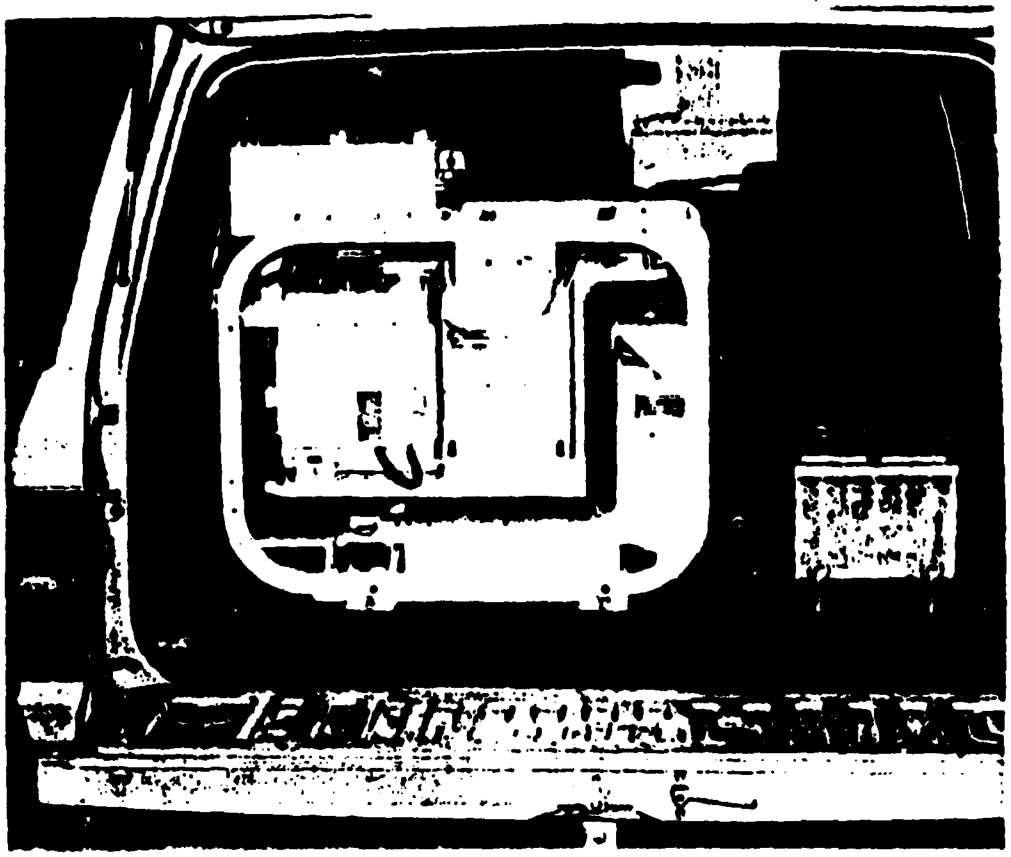


Figure 2. Typical Lass-II installation in a survey vehicle.

Figure 3. Control/display unit (CDU) of the LASS-II system.

purpose of aiding with the management of heat dissipation. Figures 1 and 2 show the LASS-II unit, and Figure 3 shows the CDU.

3. THE TEST TRAVERSE

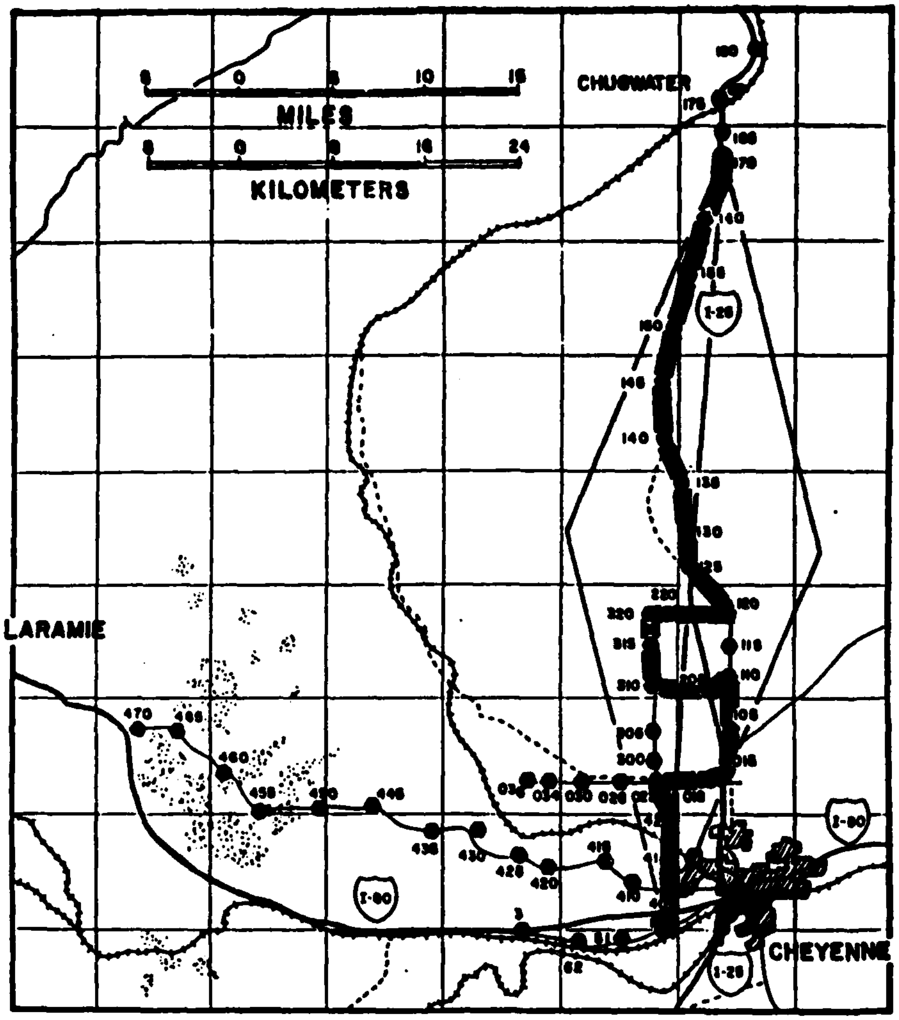


Figure 4. Cheyenne IPS Test Course and the test traverse.

The DMA-owned inertial surveying systems are operated by the Geodetic Survey Squadron (GSS) located at F.E. Warren Air Force Base in Cheyenne, Wyoming. A calibration and test course consisting, at the present time, of 49 surveyed points has been laid out along the road network to the north and west of the city of Cheyenne, known as the Cheyenne IPS Test Course.

The performance of the LASS-II system over short traverse lines (under 20 km) has been adequately tested by ITECH (1983) and RUEGER (1984), with decimeter-level accuracies reported by both. The objective of the present test was to ascertain the performance of the LASS-II system over a traverse line of operationally significant length and configuration. The traverse selected reflects the often-encountered operational scenario of a generally straight line of progress with major meandering along the way. Comprising 24 control points, it extends in a generally north-south direction from Cheyenne to just south of the town of Chugwater, with a path length of 86 km - see Figure 4. The elevation range along the traverse route is 230 m.

Since part of the overall objective was to document system accuracy under extreme conditions, the test traverse is the longest traverse which could be laid out within the confines of the Cheyenne IPS Test Course and also fully conform to the inertial traverse design criteria specified in LITTON (1982). These criteria require that (1) the traverse be fully contained within the radius of 100 km from the starting point, and (2) that no point of the traverse deviate laterally from the straight line connecting the endpoints of the traverse by more than one-third of the distance to the nearer endpoint. The Litton criteria, in effect, require that the traverse be contained within a diamond-shaped area no longer than 100 km and no wider than one-third of its length. Such diamond-shaped area which contains the test traverse is also indicated in Figure 4.

4. DESCRIPTION OF THE TEST

As is the usual case with acceptance testing, the acceptance tests of the IPS-3 and IPS-4 systems were preceded by exacting bench and road calibrations of the respective hardware, and were carried out by personnel possessing special skills and extensive experience with the operation of LASS-II systems. In contrast, the intent of operational testing is to carry it out as one would any other routine assignment, i.e., without any special preparation of the equipment and utilizing routinely trained personnel. Accordingly, the test runs made for this purpose were accomplished whenever the systems were available and without recourse to selected operators.

Four forward-and-reverse "double" runs were made over the test traverse with each system, using 3.5 minutes as the nominal zero-velocity update (ZUPT) interval. In every case, the traverse run was preceded by a one-hour alignment of the system and by a short "dummy" traverse leg. The time required to run the 86-km traverse in one direction ranged from 1 hr 35 min to 2 hr 25 min and averaged 1 hr 56 min.

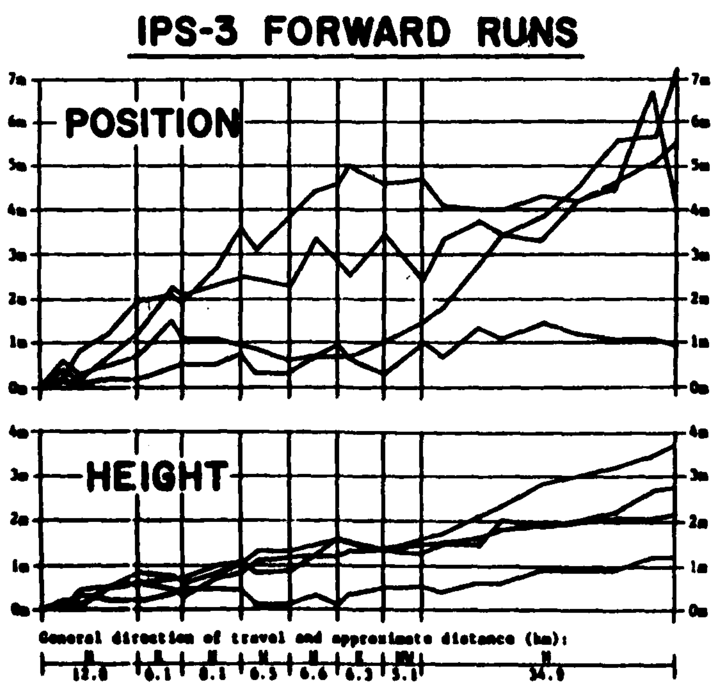


Figure 5.

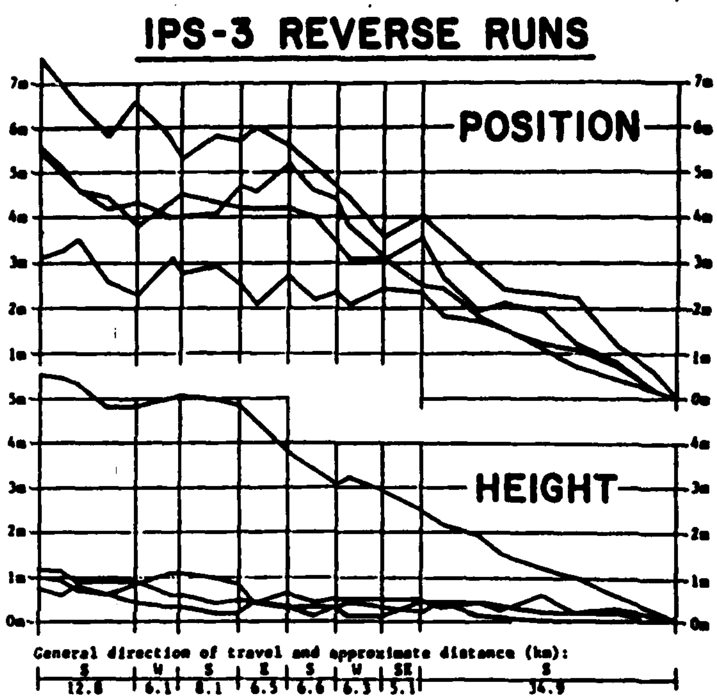


Figure 6.

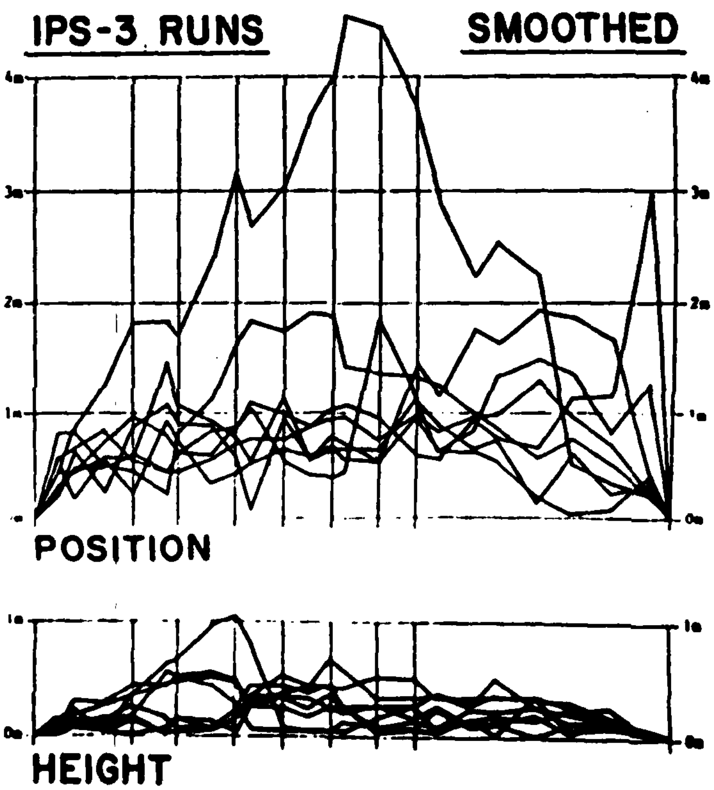


Figure 7.

5. <u>IPS-3 DATA</u>

Figures 5 and 6 show the IPS-3 unsmoothed data in the form of the *magnitude of position and height deviation* of the forward and reverse runs, respectively. Temptation is here resisted to call these "raw" data, as the data in question has been acted upon, and thereby irreversibly altered, by the Kalman filter built into the LASS-II on-line software; raw inertial data is not accessible. In each case, a 3-km dummy leg was run due south between the second and first points of traverse, whereupon the traverse proper was started due north.

Figure 7 shows the magnitude of position and height error in the corresponding smoothed (i.e., adjusted) data of the eight (four forward and four reverse) "single" runs. The strikingly better performance of the vertical channel is immediately apparent.

6. <u>IPS-4 DATA</u>

Figures 8 and 9 show the IPS-4 unsmoothed data. Of immediate note are the much larger position deviation ramps of the forward runs, not duplicated in the reverse runs, while the height deviation ramps are not significantly different from those of IPS-3.

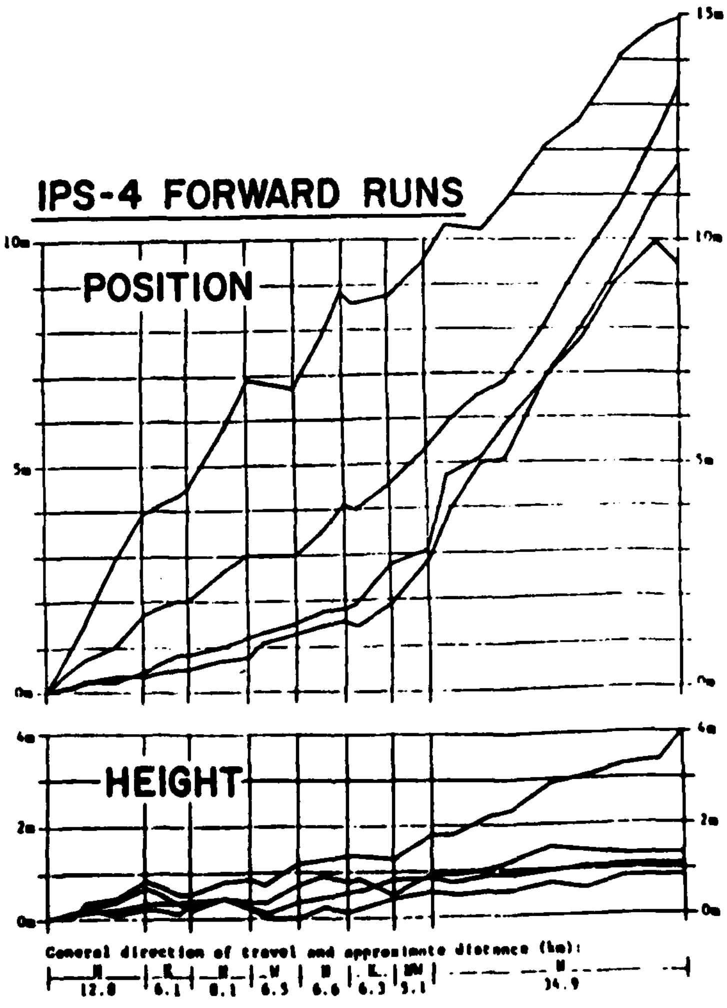


Figure 8.

8

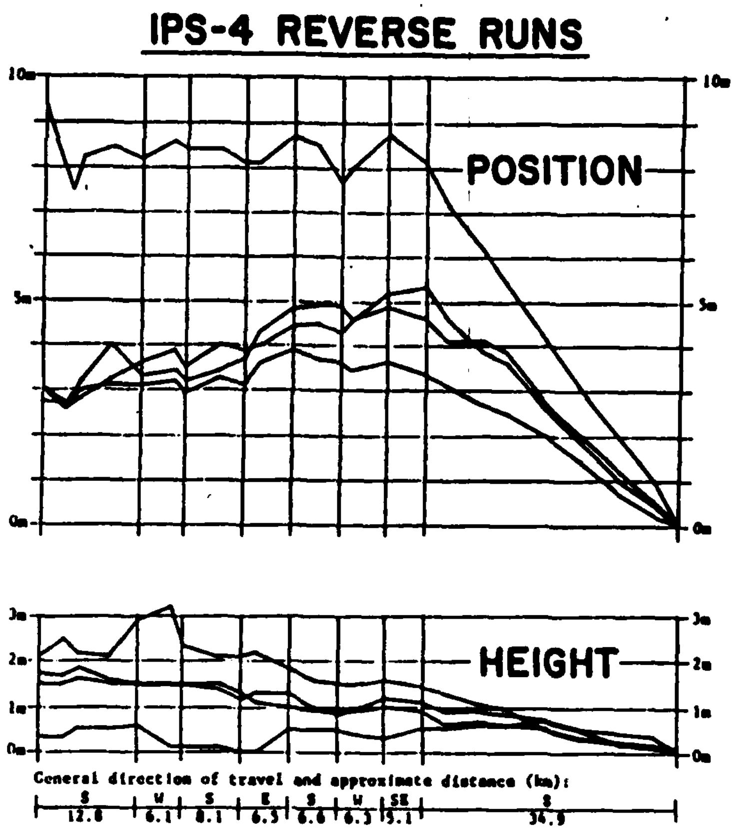


Figure 9.

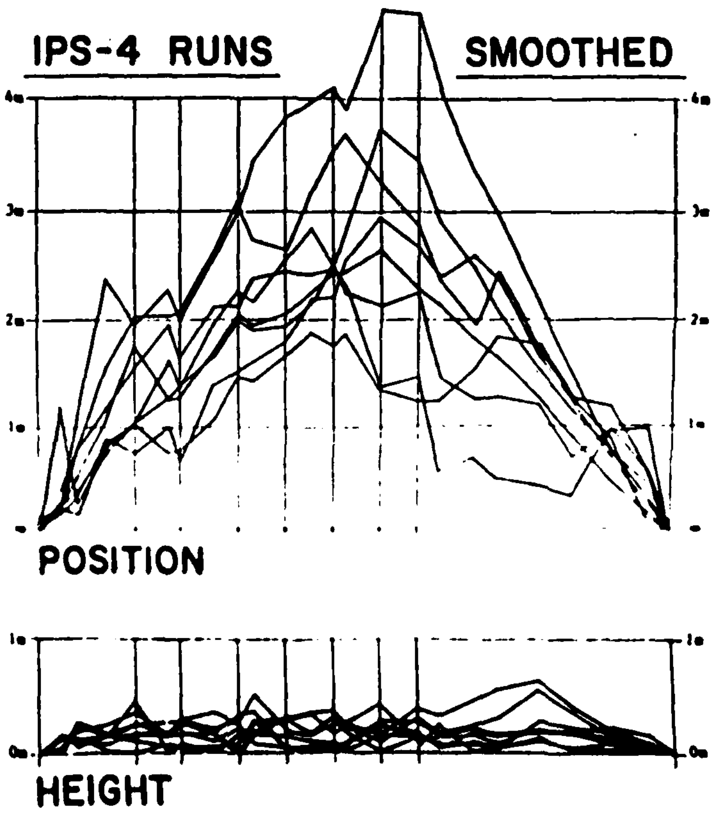


Figure 10.

Here different operators are involved and, instead of running a straight 3-km course as was the case with IPS-3, the dummy leg was run from a control point near the place of alignment over approximately 5 km of tortuous route to the starting point of the traverse. This and the likely existence of a relative position error between the two control points involved may have caused an azimuth error to be introduced into the system, as opposed to removing residual azimuth error left after alignment, which is the whole purpose of running a dummy leg.

Another possible explanation is that the large ramps in position deviation are caused by an intrinsic characteristic of the IPS-4 hardware, such as a significantly greater gyro drift. Additional controlled test runs with IPS-4 are needed to resolve this issue.

Figure 10 shows the corresponding smoothed data, with position errors somewhat greater than those of IPS-3, while height errors appear to be smaller than those of IPS-3.

7. RMS ERROR OF A SINGLE RUN

Combining the smoothed IPS-3 and IPS-4 data (total 16 single runs), root-mean-square (RMS) errors in position and in height were computed for each of the 22 intermediate points along the test traverse. These appear plotted as a function of path distance in Figure 11 together with the respective RMS error models given in LITTON (1982) and the corresponding new, "elliptical" RMS error models proposed as a result of this analysis.

RMS ERROR OF SINGLE RUN

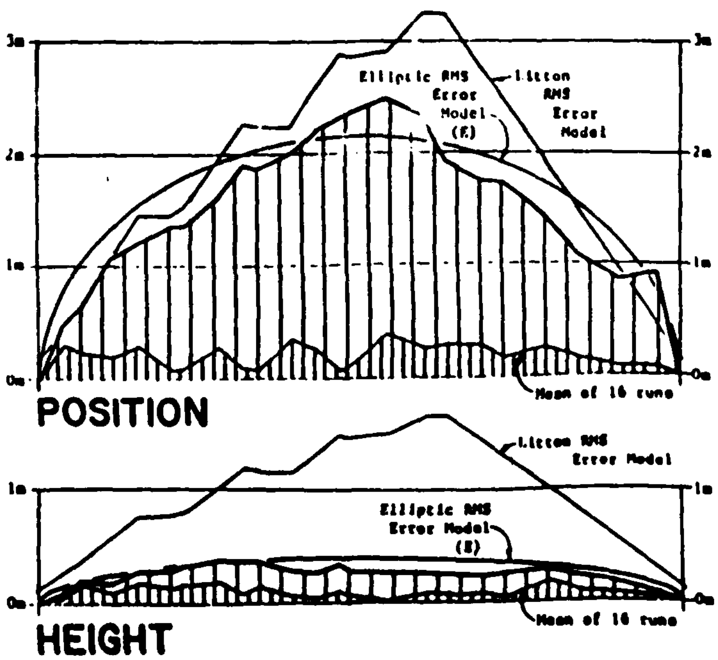


Figure 11.

The Litton RMS error models, giving the respective RMS errors (RMSE) in meters, are formulated as follows:

$$RMSE_{position} = 0.15 + \frac{S}{10,000} \qquad (1)$$

$$RMSE_{height} = 0.12 + \frac{S}{20,000} \qquad (2)$$

where S is the straight-line distance from the point of interest to the nearer endpoint of the traverse, in meters. In the case of position error, the Litton model has been found to be too optimistic for points close to the endpoints of the traverse and too pessimistic for points in the middle of the traverse, while in the case of height error the Litton model turns out to be grossly pessimistic, by a factor of 4 or 5, as is readily apparent from the lower graph of Figure 11. Also, being defined in terms of the straight-line distance S, the Litton model is not appropriate for meandering traverses.

The proposed, elliptical RMS error models, giving the respective RMS errors in meters, are defined as follows:

$$RMSE_{position} = \frac{1}{20,000}\sqrt{d(D - d)} \qquad \text{(single-run)} \qquad (3)$$

$$RMSE_{height} = \frac{1}{120,000}\sqrt{d(D - d)} \qquad \text{(single-run)} \qquad (4)$$

where d is the path distance from either endpoint of the traverse to the point of interest, and D is the total path length of the traverse, both in meters. The appropriateness and goodness of fit of these models may be judged from the graphs of Figures 11 and 13. Where the model curve falls below the observed RMS error, it must be kept in mind that the data has not been purged of outliers. In each instance, the rejection of the largest deviation in the set of 16 at each point brings the observed RMS error in line with the proposed model.

Also shown in Figure 11 is the magnitude of the position and height error of the means of all 16 (8 forward and 8 reverse) single runs. This is indicative of the noise present in the geodetic control; perhaps half of this error is attributable to uncertainties in the conventionally surveyed positions and elevations.

8. RMS ERROR OF A DOUBLE RUN

It is the standard practice to double-run inertial traverses, that is, to follow the "forward" run immediately with a run made in the opposite direction, touching upon the traverse points in reverse order, hence the name "reverse" run. The means of the respective smoothed latitudes, longitudes, and heights are then taken as improved results. In the case of height error, this improvement follows the laws of statistics for random numbers, in that the RMS error of the mean is reduced by the factor $1/\sqrt{2}$.

In the case of position error, as is readily seen in the upper graph of Figure 13, this improvement is significantly greater. The RMS error of position (where the position errors are computed as the vector sum of the deviations of the corresponding mean latitude and mean longitude pairs) is reduced by the factor 1/2 as a round figure.

MEANS OF FORWARD-AND-REVERSE DOUBLE RUNS

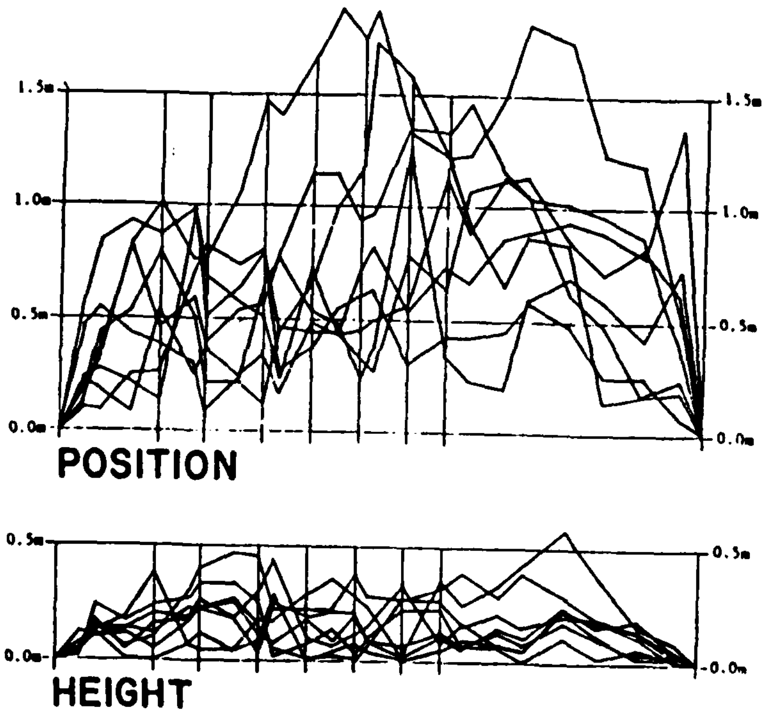


Figure 12.

RMS ERROR OF DOUBLE RUN

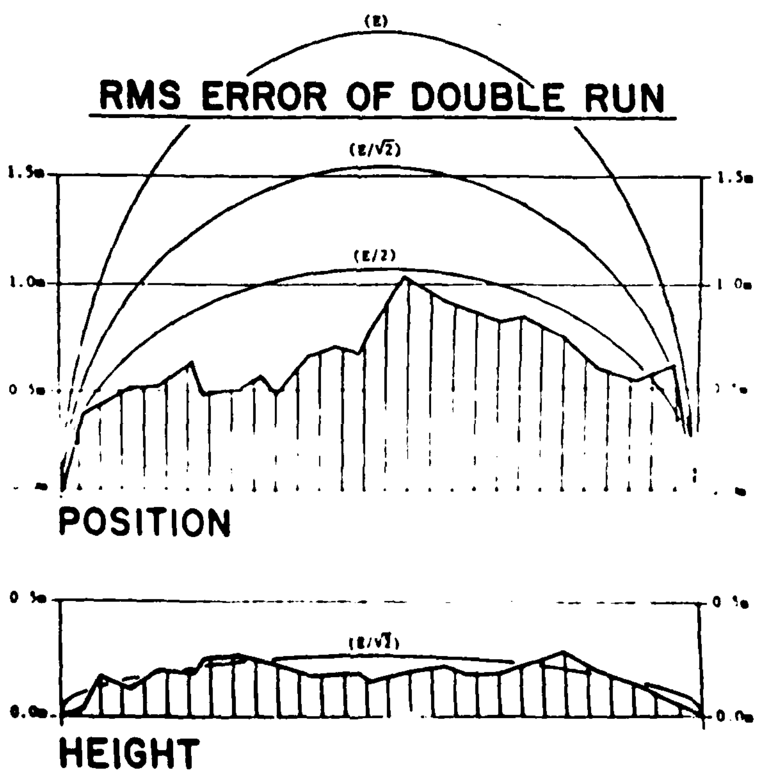


Figure 13.

Note that the letter E is used in Figures 13, 14, and 15 to identify the elliptic RMS error model curve given by equation (3) for RMS error in position and by equation (4) for RMS error in height. The other RMS error model curves shown are those corresponding to $E/\sqrt{2}$ and E/2, and are so identified.

To complete this investigation, single runs were pair-wise combined and the RMS errors of the respective means were computed for runs made (1) in the same direction with the same equipment, (2) in the same direction with different equipment, and (3) in opposite directions with different equipment. The results are shown in Figure 15, where the RMS error of a single run (see Section 7) has also been plotted for comparison.

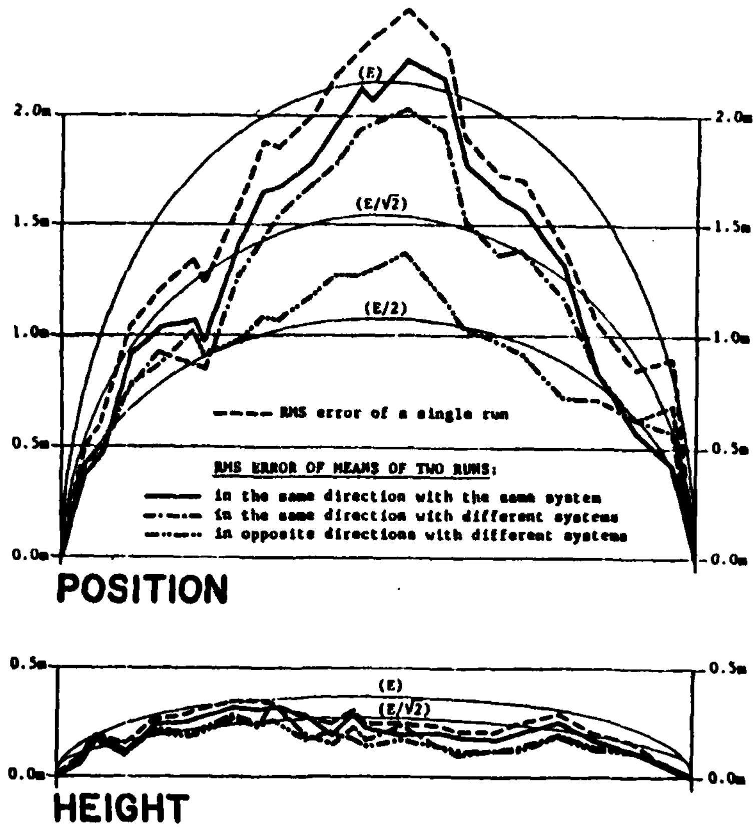


Figure 15.

The following may be abstracted from Figure 15: (1) Running the traverse twice in the <u>same direction</u> with the <u>same equipment</u> produces only a negligible improvement in either position or height accuracy. (2) Running the traverse twice in the <u>same direction</u> with <u>different equipment</u> is not much better for improving position accuracy; for height, however, it achieves accuracy improvement comparable to that of the forward-and-reverse double run. (3) Running the traverse twice in <u>opposite directions</u> with <u>different equipment</u> does achieve about three-fourths of the position accuracy improvement of the forward-and-reverse double run and height accuracy improvement, again, comparable to that of the forward-and-reverse double run.

It is apparent that the errors affecting the interpolation of position with an inertial surveying system are predominantly systematic, made up of components which are both equipment-specific and

Note that the letter E is used in Figures 13, 14, and 15 to identify the elliptic RMS error model curve given by equation (3) for RMS error in position and by equation (4) for RMS error in height. The other RMS error model curves shown are those corresponding to $E/\sqrt{2}$ and E/2, and are so identified.

To complete this investigation, single runs were pair-wise combined and the RMS errors of the respective means were computed for runs made (1) in the same direction with the same equipment, (2) in the same direction with different equipment, and (3) in opposite directions with different equipment. The results are shown in Figure 15, where the RMS error of a single run (see Section 7) has also been plotted for comparison.

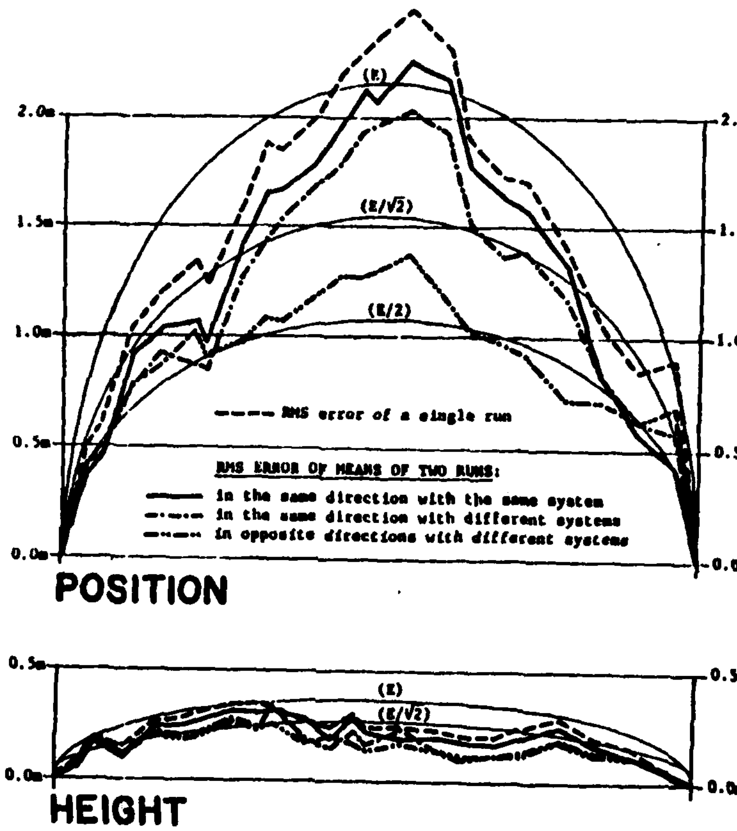


Figure 15.

The following may be abstracted from Figure 15: (1) Running the traverse twice in the same direction with the same equipment produces only a negligible improvement in either position or height accuracy. (2) Running the traverse twice in the same direction with different equipment is not much better for improving position accuracy; for height, however, it achieves accuracy improvement comparable to that of the forward-and-reverse double run. (3) Running the traverse twice in opposite directions with different equipment does achieve about three-fourths of the position accuracy improvement of the forward-and-reverse double run and height accuracy improvement, again, comparable to that of the forward-and-reverse double run.

It is apparent that the errors affecting the interpolation of position with an inertial surveying system are predominantly systematic, made up of components which are both equipment-specific and

trajectory-specific, and of such nature that their optimal reduction takes place when means are taken of the smoothed results of runs made in opposite directions with the same equipment. This would seem to indicate that the trajectory-specific component is dominant, with the gravity disturbance field the likely source. The same is observed to apply, albeit to a significantly lesser degree, to the interpolation of height. Deeper understanding of this complex error propagation must await more data and another study.

9. SUMMARY

This paper has presented, in graphical form, the errors in positions and heights interpolated with two DMA-owned LASS-II systems over a specially designed test traverse for the purpose of operational testing of the LASS-II systems. Based on subsequent data analysis, new mathematical models for the RMS errors in position and in height are proposed, which are better suited for operational configurations of inertial traverses, as well as more accurately descriptive of the RMS errors actually observed.

It must be kept in mind that the error models in question give RMS (i.e., one-sigma) values, and hence isolated errors up to three or four times their magnitude may occur. Also, these error models are specific to LASS-II systems operated in a light truck type vehicle with nominal 3.5-minute ZUPT intervals. Their validity for e.g. helicopter operation and/or longer ZUPT intervals is yet to be verified.

10. ACKNOWLEDGEMENT

The work on this paper was accomplished by the authors while assigned to the Techniques Office (GSST) of the Geodetic Survey Squadron (GSS), F.E. Warren Air Force Base, Cheyenne, Wyoming. Ludvik Pfeifer is a geodesist and project engineer for the development of inertial surveying systems. Captain Robert Tyszka, USAF, is a cartographic/geodetic officer. The inertial survey data used in this test and analysis were acquired by personnel of Geodetic Survey Section Three (GSSOG3); their essential contribution to this project is hereby acknowledged. The Geodetic Survey Squadron is a division of the Department of Geodesy and Surveys, Defense Mapping Agency Hydrographic/Topographic Center, Washington, DC.

REFERENCES

ITECH: The Litton Autosurveyor II (Dash II) - Test Results. Unpublished report. International Technology Limited, Englewood, Colorado, 1983.

LITTON: Technical Description - Litton Auto-Surveyor System II (LASS-II). Litton Guidance and Control Systems, Woodland Hills, California, 1982.

RUEGER, J. M.: Evaluation of an Inertial Surveying System. The Australian Surveyor, Vol. 32 (2), pp. 78-98, 1984.

END

FILMED

11-85

DTIC